

Canada-B.C. Conservation and Renewable Energy Demonstrations



Energy, Mines and
Resources Canada
Conservation and
Renewable Energy Branch

Energie, Mines et
Ressources Canada
Bureau de la conservation
et des énergies renouvelables



Province of
British Columbia

Ministry of
Energy, Mines and
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CONSERVATION AND
RENEWABLE ENERGY

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HASTY CREEK
SMALL HYDRO PROJECT
REPORT

Prepared by:

Small Hydro-Electrics Canada Ltd.
Silverton, B.C.

and

B.C. Ministry of Energy,
Mines and Petroleum Resources

Canada/B.C. Conservation and Renewable
Energy Demonstration Agreement

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**CANADA/BRITISH COLUMBIA CONSERVATION
AND RENEWABLE ENERGY DEMONSTRATION AGREEMENT**

The availability of secure and affordable energy supplies is a subject of national concern. It is an accepted fact that our primary energy sources - oil and natural gas - are becoming less accessible and more costly. However, Canada is well-endowed with non-renewable and alternative resources that can provide a bridge into the future.

To this end, the government of British Columbia and Canada have entered into a Conservation and Renewable Energy Demonstration Agreement. The Agreement is dedicated to the development and demonstration of conservation and renewable technologies.

The objectives of CREDA are:

- o To develop and demonstrate promising new technologies, which, when widely adopted, will exploit renewable resources, conserve energy and/or use energy more efficiently.
- o To develop broad public awareness of the potential of renewable energy and conservation technology.
- o To provide opportunities for the commercial application of the technologies within B.C.
- o To create employment in new or existing energy-related industries.

SUMMARY

This project involved connecting the Adela Corporation's 37.5 kW small hydro plant at Hasty Creek, Silverton, B.C. to B.C. Hydro and Power Authority's provincial grid. The connection was successfully accomplished, and Hasty Creek became the first privately-owned small hydro installation to supply power to the grid.

The total cost of the project was \$31,800, of which \$24,000 was provided by the Canada/B.C. Conservation and Renewable Energy Demonstration Agreement (CREDA). The capital cost of the work was \$18,800, which included: design and installation of an electrical control and protection system including metering, system protection and automatic shutdown; supply and installation of a 37.5 kW, 1200 rpm induction generator; supply and installation of electrical transmission line and transformers to link the power house to the B.C. Hydro system.

The system is expected to supply 193,000 kWh of electricity annually to B.C. Hydro, worth \$7,681 at current rates being paid by Hydro. Thus, the economics of this connection are attractive.

The demonstration showed that a privately-owned small hydro installation can safely and economically supply power to the grid. Grid-connected small hydro has the potential of delaying the need for constructing large generating facilities in B.C.

INTRODUCTION

The Adela Corporation, Silverton, B.C., in the process of installing a 37.5 kW small hydro system on Hasty Creek in Silverton, wished to connect their system to the B.C. Hydro grid for the purpose of supplying power to B.C. Hydro. This demonstration project involved the connection of the Hasty Creek system to the grid.

The Hasty Creek system would have sufficient capability to meet Adela's local needs and to supply surplus power to the grid. Through this project, it would become the first privately-owned small hydro installation to supply power to the B.C. grid.

The total cost of the demonstration project was \$31,800, of which \$24,000 was provided by the Canada/B.C. Conservation and Renewable Energy Demonstration Agreement (CREDA) and the remainder by Small Hydro-Electrics Canada Ltd., Silverton (affiliated with Adela Corp.).

The objective of the demonstration was to show that a privately-owned small hydro installation can safely and economically supply power to the provincial grid. In B.C., grid-connected small hydro has the potential to delay the need for constructing large generating facilities.

TECHNICAL DESCRIPTION

The Hasty Creek hydro installation consists of a concrete and timber diversion/intake, a metal flume and a concrete settling bay supplying a maximum flow of 3.1 cfs to a 1200 foot long 8 inch penstock, a concrete power house and a 55 h.p. impulse turbine. A net head of 198 feet results in a projected plant output of 37.5 kW. The estimated annual production will be 218,000 kWh of electricity, of which 193,000 kWh will be supplied to the grid.

The demonstration project involved:

- design and installation of an electrical control and protection system compatible with B.C. Hydro requirements, including metering, system protection and automatic shutdown;
- supply and installation of a 37.5 kW, 1200 rpm induction generator;
- supply and installation of electrical transmission line and transformers to link the power house to the B.C. Hydro system.

In the past, B.C. Hydro has been unwilling to allow grid input from small scale producers for reasons of employee safety. An understandable concern has been expressed by B.C. Hydro employees and their union regarding the safety of workers in the event that the generating plant may be supplying energy to a line assumed inactivated. The Hasty Creek Project thus uses a line-excited, line-commutated generator. In the event that the grid "goes down", power necessary for plant operation will be interrupted, the plant will be automatically disconnected from the line and the turbine will be stopped.

The control and projection system was designed and supplied by Thomson and Howe Energy Systems, Kimberley, B.C. The following description of its operation was taken from a report by William R. Thomson of that firm.

Principles of Induction Generation

a) Introduction

The principles by which induction and synchronous generators produce electricity are similar. Both types convert mechanical work into electrical power by means of rotating magnetic fields. A synchronous generator, however, is considerably more complex and difficult to use than an induction unit. Synchronous machines require additional hardware including an exciter, voltage regulator, field windings and sometimes brushes, as well as accurate synchronizing controls. This additional hardware has been customarily used to generate, maintain and synchronize an independent magnetic field. This independent, self generated field enables synchronous generators to supply stand-alone power.

The usual approach to induction generation does not provide stand-alone power and requires none of this additional equipment.

b) Rotating Magnetic Fields

The voltage of the electricity produced by a synchronous generator is regulated by the strength of the rotating magnetic field. This strength can be adjusted by means of the current through the field windings. The frequency of the power is determined exactly by the rotational speed of the field.

An induction generator, on the other hand, is unable to create its own magnetic field. If this type of generator is brought up to speed in electrical isolation from a utility, no electric power will be delivered because no voltage can be produced in the absence of a magnetic field. An induction generator will only generate if the magnetic field is imposed on it via an outside source, for instance by connection to a utility.

Induction generators hence are easy to connect to a utility, as indicated in the following case:

An induction generator, starting from a stand-still condition, is connected across a utility supply. The utility voltage will create a rotating field inside the generator. This field will pull at the rotor and attempt to accelerate it. Once this field is established, the generator is

actually acting as a motor, converting electrical power into mechanical work and accelerating the rotor, shaft, turbine et al. If the rotor is brought up to speed and revolves at exactly the same speed as the rotating magnetic field, no power is transferred either one way or the other. If the water is now applied to the turbine prime mover, the generator will speed up in the direction of rotation, and the rotor will start to turn faster than the magnetic field, pulling at the field and trying to accelerate it. When this happens, the generator is now supplying power, converting mechanical power into electrical power across the difference between the magnetic field rotational speed and the actual rotor mechanical speed.

c) Synchronization with a Utility

Unlike a synchronous motor rotor, which is physically locked into step to the rotating magnetic field of the generator (and hence the term "synchronous"), an induction motor rotor actually overspeeds when generating power, and underspeeds when acting as a motor. An induction machine rated at 1200 rpm would actually rotate at perhaps 1120 rpm acting as a motor at full load and 1280 rpm acting as a generator at full load. The "softness" of an induction generator's speed regulation can be exploited in simplifying the control hardware required, since the generator need not even be at synchronous speed before connecting the generator to a utility, unlike a synchronous machine's rigid requirements for exact speed and angular position when being connected to a utility grid.

d) Summary of Benefits and Deficiencies

The benefits may be itemized as follows:

1. Greater safety due to induction generation's almost certain inability to support stand-alone excitation.
2. Greatly relaxed synchronization requirements.
3. Minimal electrical contribution to short circuit faults.
4. Minimal mechanical stresses during short circuits.
5. Reliability and availability of standard industrial generation and switchgear components.
6. Simpler, more fool proof start up and shut down procedures.
7. Simpler and less expensive auxiliary equipment.

The deficiencies of induction generation are as follows:

1. Requirement for VARS for excitation support.
2. Lack of a stand-alone generation capability.
3. Lack of the ability to stabilize utility voltages.
4. Loss of "slip" energy.

Description of the Hasty Creek Generation Plant

a) Utility Connection

B.C. Hydro power service can be provided at roadside 400 feet away from the generator installation. Three pole mounted 15 KVA transformers step the 13.8 KV primary voltage down to the 600 volt three phase power that is suitable for supply of the generator. The 600 volt power is brought down the transformer pole to in/out B.C. Hydro metering, consisting of two meters in series. The meters are designed to read power flows in opposite directions, one in and one out. The power is then delivered to a fused disconnect switch that provides the point of delivery to the customer's system. The connection is then via an underground cable up the hill to the generator site.

The B.C. Hydro line crew has the ability to open and lock the pole mounted disconnect switch during maintenance work for additional peace of mind.

b) Electrical Equipment

The underground cable is terminated in a second disconnect switch, which is connected to the splitter. All electrical connections to the generator and loads are made at this splitter. The connection to the generator is made through a standard industrial type motor starter which features built-in motor protection, magnetically held contacts, a control transformer, and current and voltage sensing transformers. The generator side of this starter is also connected to a three phase capacitor for power factor correction to above 90%. The generator is actually a standard industrial induction motor with only the possible modification of a smaller cooling fan. It should be noted that this generator and the switchgear mentioned above constitute the same configuration as is used in thousands of industrial installations in B.C., the only difference being that this installation will supply instead of consume power.

c) Water Control System

The water for driving the impulse type Pelton Wheel turbine is delivered at high pressure through a manually controlled valve and hence through a nozzle at high velocity. The water stream is normally deflected away from the turbine when the generator is off line by means of a pneumatic/hydraulic operated deflector. This deflector actuator is operated into the deflecting position by means of an air receiver under pressure. This ensures that fail-safe shut-down is achieved upon total loss of power.

d) Electrical Control and Protection Overview

The standard sequence for starting the plant up is as follows. Assuming that all three phases of utility power are on, that the starter overloads are not tripped, and that no trips are showing on the Induction Protection Unit (IPU), or the Synchronizing Control Unit (SCU), the operator may press and hold the start button to start-up the plant. Immediately a solenoid operated valve will operate to slowly disengage the deflector, allowing water to reach the turbine. When the generator reaches about 95% of synchronous speed by accelerating on water power, a speed sensor on the generator will signal to the SCU, and the generator will be connected to the utility (at about 100% speed because of a short delay). If the operator releases the start button at any time up to when the generator is actually connected to the utility, then the start-up is aborted and the system will immediately shut-down. Once on-line, the operator can shut the plant down by pressing the stop button. Immediately the generator is disconnected and the water turned off.

The system also has a facility for unattended start-ups after complete utility power outages. This feature, if enabled, allows the generator to try one start-up only, 10 minutes after restoration of power.

The Induction Protection Unit (IPU) is wired to quickly shut the plant down if any of the following conditions exist: if the line voltage rises above or drops below preset limits on the monitored phase; if the line frequency deviates above or below preset limits on the monitored phase; if the generator ceases to produce power; or if the generator phase current magnitude is imbalanced.

The voltage and frequency limits help to ensure a rapid shut-down during a power outage situation. The loss of power trip helps to ensure that the generator is not allowed to motor if the water fails. The current magnitude imbalance trip is a sensitive test for both line voltage imbalance and for single phasing conditions on the B.C. Hydro supply service.

The Synchronizing Control Unit also provides over and under speed trips based on the actual mechanical speed of the generator.

The loss of power and current imbalance trips are disabled for a few seconds at the time of start-up to allow stabilization.

Detailed Protection Description

a) Overcurrent Generator Protection

Standard industrial induction motor protection hardware is used to provide the necessary generator protection. The three phase overloads are thermal devices that operate from heating elements inserted into each line connection from the generator. The ampacity rating of these elements is reduced from what would normally be required for an induction motor of this size because of three reasons: the line currents are lower because of the power factor correcting capacitor; the motor is somewhat oversized to obtain higher efficiency; and no in-rush current is required with this design. The fuses are the same type that would be used for an industrial motor installation, but somewhat smaller than normal.

b) Under/over Voltage Protection

Symmetrical voltage relaying protection is provided on two of the three phases by means of a potential transformer and also the control transformer. The IPU provides the usual protection during symmetrical over or under voltage conditions by releasing a normally held contact in the motor stop/start circuit. Symmetrical over voltages are also detected by the auxiliary voltage relay. Symmetrical under voltages are also detected by the following equipment: the motor contactor coil; the water control solenoid; and the power supplies in both the IPU and the SCU that hold their respective relays normally energized.

A discussion of asymmetrical over/under voltage conditions (e.g. single-phasing) is available in part f) of this section.

c) Under/over Frequency Protection

The frequency of the power is monitored on one phase only by means of an analog circuit. The 60 hertz power is filtered and then converted to a voltage that is monitored for deviations.

d) Under/over Speed Protection

Backup to the UF/OF function is obtained by means of a tachometer attached to the generator or turbine shaft. The SCU uses the signal from this unit to determine the correct synchronizing point and to also provide protection for the generator and turbine against over speed.

e) Loss of Water Protection

The IPU includes a single phase watt monitoring circuit that provides an indication of the output of the generator. The purpose of the circuit is to indicate that something is wrong with the water system by shutting the generator down, and also to avoid wasteful motoring conditions upon total loss of water.

f) Phase Imbalance - Single Phasing Protection

The impact of voltage imbalances on the operation of Hasty Creek may be considered in two parts: when the generator is on line; and when the generator is shut down but attempts a restart either automatically or manually.

An operating induction motor or generator is very sensitive to voltage imbalances on the terminals. The full transient reactance of the generator is available to attempt to correct the voltage imbalance by creating a line current imbalance. In effect, the magnetic field "supported" by the higher voltage phase or phases is drawn upon to maintain voltage in the lower voltage phase. Reactive flow will increase from the higher voltage phase, and the lower voltage phase may actually obtain VARS from the induction unit, all other things being equal. The IPU monitors the current balance on the generator to detect this condition. The tripping point function can be set from between 110% and 150 of I_{max}/I_{min} , which should accurately detect voltage imbalances from 2% to about 10%. The imbalance function also reliably prevents the generator from back-feeding on one phase while remaining connected to the utility on the remaining two phases as this is an extreme case of voltage imbalance. The possibility that both the reactive and real power loading on the open phase would exactly match the phases of the generator still connected to the utility is remote.

If the generator is already shut down, then the sensitive detection of voltage imbalance available by the generator itself is not available. Restarts of the generator are inhibited by means of voltage relays on two of the three phases, set with enough sensitivity to detect loss of voltage or single phasing on any one of the three phases.

g) Trip Maintenance

The IPU trips are normally lost if the voltage on both the A-B phase and the B-C phase drop below about 30%. The generator will of course remain off until restarted either manually or automatically and such restarts are inhibited until restoration of voltage. If determination of trip cause is important after complete power interruptions, then an optional battery may be fitted to maintain the trip indication.

The generator current overloads are of the manual reset type and will prohibit restarts if tripped and not reset.

h) Discussion of Stand Alone Excitation

Induction generators are capable of maintaining production of power without connection to a utility grid if the following requirements are precisely met:

1. Initial connection to the utility to establish generation.
2. A source of VARS to maintain the necessary excitation of the magnetic field.
3. A sink for the power to be generated.

The Hasty Creek System is designed to avoid the possibility of stand alone generation in the following ways:

1. Insufficient VARS are supplied on site to maintain excitation.
2. The total load connected would have to constantly be equivalent to the output of the generator to within an accuracy of from 20% to 1%, depending on the limits selected for the under/over frequency trip function.
3. The total VARS would have to closely match the required excitation, otherwise the under/over voltage relaying would trip.
4. The above conditions #2 and #3 even if fulfilled would also have to be highly symmetrical between the three phases, otherwise the current imbalance function would trip.
5. The system includes a disconnect switch to ensure absolutely safe isolation for line work.

DEALINGS WITH B.C. HYDRO

In September 1980, the B.C. Hydro board voted in favour of purchasing non-firm energy from private producers, subject to conditions.

Dealings with B.C. Hydro thus involved two issues:

- 1) determination of the rate to be paid to Adela Corp., which obviously affects the viability of the project; and
- 2) the technical requirements to be imposed by Hydro for control and protection of the generating plant, B.C. Hydro facilities and employees.

Small Hydro-Electrics Canada Ltd. considered that B.C. Hydro took an unnecessarily demanding approach to the control and protection question. B.C. Hydro specified that the Hasty Creek system must disconnect from the grid, with turbine shutdown, in the following events:

- single or multi-phase over/under voltage
- single or multi-phase over/under current
- single or multi-phase over/under frequency
- current imbalance
- local fault clearing over-ride
- low-voltage on startup
- power factor correction
- negative sequencing

In September 1983, B.C. Hydro carried out on-site performance and acceptance testing of the control and protection system. They installed high-speed chart recorders and other equipment, and used a systematic test procedure including simulated grid failures. In all tests the control and protection system met B.C. Hydro's requirements.

In July 1982, Adela Corp. was informed by B.C. Hydro of their intent to purchase energy at a particular rate. A contract proposal was sent to Adela in October 1982 which was unacceptable to Adela. In November 1983 Adela Corp. and B.C. Hydro signed a Power Purchase Agreement. The Agreement is only for a one-year period but B.C. Hydro has assured Adela that the term will be extended for another year. B.C. Hydro is paying Adela 3.98¢ per kWh supplied.

FINANCIAL ANALYSIS

The project budget was as follows:

Project planning & design	\$ 2,400
Supervision & administration	1,600
Direct labour & equipment installation	3,800
Power house equipment, installed	6,600
Transmission line & ancillaries	4,400
	<u>\$18,800</u>
Monitoring & information transfer	<u>13,000</u>
TOTAL	\$31,800

\$24,000 was provided by CREDA and the remainder by Small Hydro-Electrics Canada Ltd.

It was estimated that 193,000 kWh of electricity would be sold annually to B.C. Hydro, at 1.4¢ per kWh. B.C. Hydro is now paying 3.98¢ per kWh. Thus, if Adela supplies the full amount of power, its first year revenues would be $193,000 \text{ kWh} \times \$0.0398/\text{kWh}$
= \$7,681

The simple payback period based on the capital cost of the equipment and assuming no annual expenditures for maintenance, etc.,

$$= \frac{\$18,800}{\$7,681/\text{year}}$$

$$= 2.5 \text{ years}$$

PERFORMANCE

The control and protection system is operating well. The hydro-electric plant itself was subject to minor mechanical malfunctions in the intake manifold and one needle nozzle system which resulted in loss of production. These malfunctions have been substantially corrected.

Estimated production for the first year of operation is 181,000 kWh, for revenues of \$7,040. Production for year 2 is estimated to be 264,000 kWh.

CONCLUSIONS

The Hasty Creek project proved the technical merit and financial viability of connecting a small hydro plant to the provincial grid. The economics will be different for specific sites depending upon creek hydrology, distance from existing transmission lines, etc. However, the concept has now been demonstrated to be viable in British Columbia.